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SHORT COMMUNICATION

Calorie intake misreporting by diet record and food frequency questionnaire compared to doubly labeled water among postmenopausal women

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Objective: We assessed the extent of energy misreporting from the use of a self-administered 7-day diet record (7-DDR) and a widely used food frequency questionnaire (FFQ) compared to total energy expenditure from doubly labeled water (DLW) in a group of postmenopausal women.
Design: At baseline, 65 healthy postmenopausal women were instructed to fill out the National Cancer Institute's (NCI) FFQ and a 7-DDR. Average total energy expenditure using the DLW method was also performed at baseline.
Results: On average, the women underestimated total energy intake compared to total energy expenditure assessed from DLW by 37% on the 7-DDR and 42% on the FFQ.
Conclusions: These findings suggest that the interpretation of findings from the 7-DDR- and FFQ-based energy-disease association studies in postmenopausal women needs further evaluation.
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Introduction

Nutritional epidemiologists have long recognized that self-reported dietary intake data underestimate energy intake, but uncertainty remains about its magnitude in specific populations. A population of interest is postmenopausal women because although natural menopause represents a normal aspect of aging, it is also associated with increased risk for a variety of diseases such as osteoporosis (Eichner *et al*., 2003), type 1 diabetes (Dorman *et al*., 2001), cardiovascular diseases (Gorodeski, 1994), and breast cancer (Edwards *et al*., 2002). Because numerous studies use data from self-reported questionnaires to assess the association between diet and disease in postmenopausal women it is important to understand the magnitude of dietary intake misreporting in this population. Energy intake is a very critical component of the relationship between diet and disease because nutritional epidemiologists only consider the associations with nutrients as primary if the effects are independent of caloric intake resulting from differences of body size and energy expenditure level (Willett and Stampfer, 1996). For this reason it has become very popular (if not mandatory) to adjust for total energy intake measured

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by dietary questionnaires in multivariate models to assess the independent effect of nutrients on disease. The limitation is that dietary questionnaires may estimate energy intake rather poorly (Black *et al*., 1997; Hill and Davies, 2001; Subar *et al*., 2003). Thus, it is important to understand the extent of energy intake misreporting from dietary questionnaires and this can only be achieved when the comparison is made to a well-established biomarker for energy intake. Identification of the quantitative characteristics of the misreporting of energy intake may be useful to develop better diet questionnaires, to adjust for dietary measurement error, and to aid in the interpretation of epidemiological studies of diet–disease associations in postmenopausal women.

The purpose of our study was to assess the extent of energy intake misreporting computed from a 7-day dietary record (7-DDR) and the widely used National Cancer Institute's food frequency questionnaire (FFQ) (Subar *et al*., 2001) to doubly labeled water (DLW), an unbiased reference biomarker for energy intake. The dietary intake data was used for two purposes in this study: to validate dietary instruments (for energy intake only) and to estimate a caloric intake level to start participants on for the controlled dietary portion of the study. We used two different dietary assessment methods – one used to estimate habitual intake (FFQ) and the other used to estimate short-term intake (7-DDR) – because many reports on diet and disease use data from these methods. As the memory component of these two techniques is different, it is expected that the extent of misreporting will differ between these two methods. Very few published reports exist on the comparison of energy intake estimate from dietary questionnaires to unbiased biomarkers of energy intake such as DLW.

Methods

This study was conducted as a cross-sectional analysis within the baseline segment of a randomized, crossover design in which postmenopausal women ($n=65$) subsequently consumed 0 (control), 15 (one drink), and 30 (two drinks) grams alcohol (ethanol)/day for 8 weeks each as part of a controlled diet to assess the effects of moderate alcohol consumption on serum hormone and lipid profile. Details of the study design and procedures have been previously published (Dorgan *et al*., 2001; Baer *et al*., 2002). Postmenopausal women were recruited by advertisement from the communities surrounding the Beltsville Human Nutrition Research Center, Beltsville, Maryland, USA. The eligibility criteria were (1) women $\geqslant$50 year of age, (2) postmenopausal (last menses $\geqslant$12 months before the study started, follicle stimulating hormone $>$40 000 IU/l, natural menopause or hysterectomy with at least one ovary intact), (3) not receiving hormone replacement therapy (HRT), (4) not taking prescription medications that might interfere with the study, (5) willing and able to consume the diet prepared or approved by the Center and no other foods or beverages, (6) have a body mass index (BMI) of between 90 and 140% of ideal, and (7) have no personal or parental history of alcohol abuse. The National Cancer Institute's Institutional Review Board and the Committee on Human Research of the Johns Hopkins University Bloomberg School of Hygiene and Public Health approved this study.

At baseline, the subjects were instructed by the study dietitian to fill out National Cancer Institute's (NCI) diet history questionnaire (DHQ) (http://riskfactor.cancer.gov/DHQ/), a widely used FFQ (Subar *et al*., 2001). This FFQ measured habitual dietary intake within the last 12 months. Subjects were also instructed to record in detail all foods eaten during the next 7 consecutive days in a 7-DDR. Thus, data from the 7-DDR are based on estimates (not weighed) only. The 7-DDR measured short-term dietary intake. Both of these approaches involved self-administered questionnaires and thus the data are based on estimates only. The questionnaires were returned to the study dietitian who reviewed each questionnaire for accuracy and data entry. The NCI FFQ used in this study consisted of 124 food items and included both portion size and dietary supplement questions. It took about 1 h to complete and was designed, based on cognitive research findings, to be easy to use (http://riskfactor.cancer.gov/DHQ/). The dietary data were analyzed using the software program Diet*Calc. The FFQ food group database is based on national dietary data from the US Department of Agriculture's Continuing Survey of Food Intake by Individuals (CSFII).

Average total energy expenditure using the DLW method was also performed at baseline. To measure free-living energy expenditure, background urine samples were collected prior to dosing with oxygen-18 and deuterium ($H_2^{18}O$: 0.14 g/kg body weight, ^2H_2O: 0.70 g/kg body weight). The percentages of the isotope in each dose were, respectively, 6.45 ($H_2^{18}O$) and 34.58% (^2H_2O). Following dosing, multiple urine samples were collected during a 14-day period. Total energy expenditure was calculated from the decay kinetics of urinary isotope excretion during the 14-day period (Racette *et al*., 1994). Isotope kinetics were determined by using a multipoint calculation technique (Seale *et al*., 1989; Seale *et al*., 1990; Seale *et al*., 1993). The ^2H and ^{18}O zero-time intercepts and clearance rates (k_h and k_o) were calculated using least-squares linear regression on the natural logarithm of the isotope concentration as a function of elapsed time from dose administration. The zero-time intercepts were used to determine the isotope pool sizes at the time of the dose. The ^2H and ^{18}O pool sizes were used to estimate total body water (^2H pool size/1.04 and ^{18}O pool size/1.01, respectively). The production rates of carbon dioxide (rCO_2) and water (rH_2O) from the isotope clearance (k_h and k_o) rates and total body water were calculated by the method of Seale *et al*. (1990).

The women in this study were part of a controlled feeding trial, and their weights were measured daily and their caloric intakes were adjusted for weight maintenance.

Pearson and Spearman correlations between the total energy expenditure from DLW and total estimated energy intake from the 7-DDR and FFQ were determined. Comparisons of DLW and the questionnaires were accomplished by regressions of one measure on another. Student's *t*-tests were used to evaluate the mean differences between DLW and both questionnaires. Bland–Altman plots were made to compare the differences between energy intake form diet questionnaires and energy expenditure from DLW. All *P*-values are two-sided. All statistical analyses were performed using PC SAS (version 8; SAS Institute Inc., Cary, NC, USA).

Results and discussion

The women ($N = 65$) had a mean age of 59.9 years (s.d. ± 7.5) and a mean BMI of 27.73 kg/m^2 (s.d. ± 5.66). The women reported their race as follows: 49 whites, 12 blacks, 2 Asians, and 2 others. Table 1 shows characteristics of the study participants and Table 2 shows the study results. Compared to the DLW total energy expenditure estimate, the women (on average) underestimated total energy intake by 37% on the 7-DDR and by 42% on the FFQ. When we stratify the women by indices for normal weight (BMI $\leqslant 25$ kg/m^2) and overweight (BMI > 25 kg/m^2), significant underestimation of energy intake compared to DLW remained in both weight categories for both questionnaires, but overweight women tended to underestimate energy intake more than normal weight women. Underestimation of energy intake from both questionnaires was similar for women < 60 years and women $\geqslant 60$ years (data shown).

Table 1 Characteristics of the study participants ($N = 65$)

Characteristic	*Mean (s.d.)*	*Median (Inter-quartile range)*	*Range*
Age (years)	59.9 (7.5)	58.0 (10)	49.2–78.8
Height (cm)	163.3 (6.6)	162.6 (9.0)	148.1–179.9
Weight (kg)	74.0 (16.2)	73.2 (23.0)	42.1–117.4
BMI (kg/m^2)	27.7 (5.6)	27.4 (7.6)	17.7–42.5
Others	*No. (%)*		
BMI $\leqslant 25$ kg/m^2	21 (33%)[a]		
BMI > 25 kg/m^2	42 (65%)		
Race			
White	49 (75%)		
Black	12 (18%)		
Asian	2 (3%)		
Other	2 (3%)		

[a]7-DDR missing on two subjects.

Food frequency questionnaires are designed to measure a person's habitual dietary intake over a defined period of time, are relatively inexpensive and easy to administer, and, as a result are widely used in epidemiological studies of diet-disease relationships. Because of measurement error associated with FFQs, researchers have utilized more expensive and time-consuming diet records and 24-h diet recalls as reference instruments to calibrate the FFQs. Only a small number of studies have been reported which related DLW, an unbiased reference biomarker of total energy intake, to energy misreporting from diet records and the 24-h diet recall (Seale and Rumpler, 1997; Kroke *et al*., 1999; Black *et al*., 2000; Trabulsi and Schoeller, 2001; Weber *et al*., 2001; Hill and Davies, 2002; Subar *et al*., 2003). Most of the previous studies, except the Observing Protein and Energy Nutrition (OPEN) study (Subar *et al*., 2003) were small. The OPEN study, the largest study ($N = 484$, men and women) to date found that compared to DLW, men under-reported energy intake on 24-h recalls by 12–14% while women under-reported by 16–20%. On the FFQ, men under-reported by 31–36% and women by 34–38% (Subar *et al*., 2003). Our study ($N = 65$ postmenopausal women) is the second largest such study to date and the first specifically in postmenopausal women to assess energy misreporting on the food records and an FFQ compared to DLW. On average, these women underreported total energy intake by 37% on the 7-DDR and 42% on the FFQ. Our study supports the findings of the OPEN study (Subar *et al*., 2003) and the smaller studies (Kroke *et al*., 1999; Trabulsi and Schoeller, 2001; Weber *et al*., 2001; Hill and Davies, 2002) which found substantial underreporting of energy intake from food records and FFQs.

The Bland–Altman plots (Figures 1 and 2) show that underestimation tended to increase with increased consumption. This tendency has been noted in previous studies (Subar *et al*., 2003). Consumption of more foods may make it more difficult to report accurately because of the added

Table 2 Comparison of total energy expenditure from doubly labeled water (DLW) and total energy intake from 7-day diet record (7-DDR) and the NIH diet history (FFQ) in postmenopausal women ($n = 65$)

	Value[a]	*Difference*[b]	R^{2c}
DLW	2564 ± 687 (2560)		
7-DDR	1612 ± 348 (1556)	-947 ± 671 (967)*	0.098 (raw) 0.0696 (log 10 transformed)
FFQ	1471 ± 771 (1345)	-1083 ± 891 (1120)*	0.067 (raw) 0.027 (log 10 transformed)

[a]Mean, standard deviation (median).
[b]Differences between energy expenditure (EE) from DLW (gold standard) and the other methods (test). A negative value indicates an underestimation of EE relative to DLW.
[c]Regression of each measure against DLW.
*Significantly different from zero, $P < 0.05$.

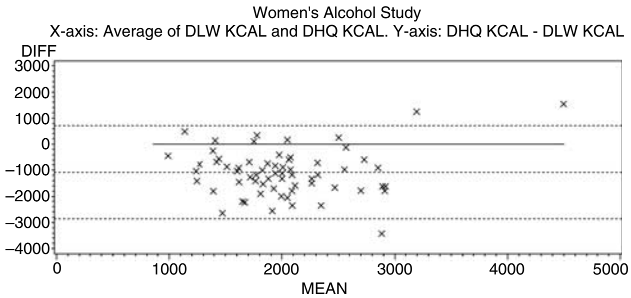

Figure 1 Bland–Altman plot: Differences between energy expenditure measured by DLW and energy intake measured by the FFQ plotted against the mean of the two measurements (energy expenditure from the DLW and energy intake from the FFQ).

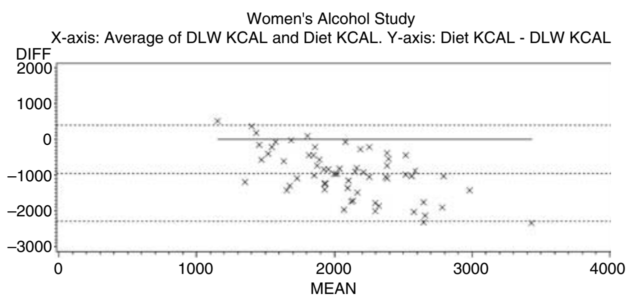

Figure 2 Bland–Altman plot: Differences between energy expenditure measured by DLW and energy intake measured by the 7-DDR plotted against the mean of the two measurements (energy expenditure from the DLW and energy intake from the 7-DDR).

burden to remember more foods or a greater number of portion sizes. Alternatively, under-reporting may reflect the stigma associated with obesity and the societal pressure to consume less.

Our study was limited by its cross-sectional design. The DLW was administered only once and therefore it might not adequately reflect long-term energy intake as queried by the FFQ. The findings from our study and other studies suggest that researchers using dietary questionnaires to assess diet–disease relationships need to carefully consider the implications of substantial under-reporting of energy intake by the population being studied. From a practical standpoint, dietary questionnaires remain necessary for large-scale epidemiology studies. In addition, to translate the success of dietary intervention efforts, dietary questionnaires are required to measure behavioral changes in targeted populations. The selection of the appropriate diet questionnaires, therefore, involves both scientific and practical considerations. Validation studies of diet questionnaires are and will remain a critical prerequisite for the proper interpretation of dietary data from large epidemiological studies, and permit adjustment of measurement errors through the use of statistical modeling. A limiting issue in this field is the widespread disregard for conducting proper validation studies of diet questionnaires prior to use in epidemiology studies.

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